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Value Stream Mapping and Process Mining: A Lean Method Supported by Data Analytics

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Abstract

The analysis and further the reorganization of an order-production is a typical scope of application of a value stream mapping. Value stream mapping is a lean-management method to map the current state of a series of processes that are necessary to manufacture a product or provide a service. The ever-increasing digitalization emphasizes the importance of the information flow. Besides the material flow, the information flow is the second focus of value stream mapping. It is needed to get valuable insights into the production process by applying state-of-the-art data analytics methods. Process Mining is a possible method to analyse (business) process and process sequences based on event logs. This paper illustrates a method of combining conventional value stream mapping and Process Mining. While value stream mapping shows the material and information flow as the people think it is, Process Mining shows how they are, based on the data fingerprint. The comparison of the two outcomes allows conclusions for the following value stream design with a special focus on the use of data for Industry 4.0 applications. The application of both methods to an order-production enables to present results and compare both as well as present advantages and disadvantages.

Keywords

Value stream mapping (VSM); Process Mining; Lean 4.0

1. Introduction

The improvement of processes to increase efficiency is an ongoing goal in companies. Lean Management is a well-known and established philosophy to achieve that. For this purpose, value stream analysis is one of the best-known methods.

Industry 4.0 pursues, among other goals, the same goal of increasing efficiency and consequently value competitiveness. In the last years, there was an increased focus on how Industry 4.0 can help to achieve these goals. The major question is how the principles of Lean Management and Industry 4.0 support and substitute one and another. Consequently, one may be able to use Industry 4.0 and its tools to enhance the tools of Lean Management.[1]

The flow principal and one-piece flow are fundamentals of Lean Management. To enable them the value stream mapping is an important tool, to identify, analyse and improve the value stream. It is done by hand and is therefore rather time-consuming to be done on a regular basis.[2] Using principles of Industry 4.0 it was tried to streamline the process of the analysis and mapping of the value stream.

Agility and flexibility are besides increasing of efficiency a major factor to push Industry 4.0. It uses the possibilities of digitalization to satisfy these goals. The increased demand for custom-made products to low prices encouraged companies to further diversify their portfolio with sheer endless variants. This confronts the planning and production with the challenges of lot-size-one production and one-piece flow. The horizontal and vertical integration of IT-Systems and the followed increased amount of data enables new possibilities to make a lot-size-one production cost-efficient. A wide variety of data analysis methods are the tools that help to tackle the tasks at hand in the future.[3] Process mining is a relatively new method to map and improve processes based on the traces of data [4].

In this paper, a method is presented to combine Process Mining, as a method of possible through the advances of Industry 4.0 and value stream mapping, as a method out of the toolbox of Lean Management. The case study is the production of a contract manufacturer. They are faced with lot size 1 manufacturing ever since. A highly variable product mix leads to a constantly changing main material flow. To analyse and map the flow to improve upon it or use it for better planning is a near-impossible task to perform by hand. Therefore, the combination of Process Mining and value stream mapping is presented to remedy the disadvantages of the classical value stream mapping.

2. Theoretical Background

2.1 Value stream mapping in Order-Production

The idea of lean manufacturing, i.e. structuring along the value stream and minimizing waste, has found its way into many companies. Value stream mapping (VSM) is a widely used method to support these actions. Material and information flows are represented in a standardized way, the potential for improvement can be derived, and the target state can be developed.[5] Originally, the conventional VSM was designed by Toyota for series-production[6] and the focus is on the series production representing logistical targets, e.g. the execution time, process time, set-up time, cycle time, machine reliability, and inventory.[5] The timeliness is neglected, although most users see their main goals when applying the method in the recording of the lead time and the timeliness.[6], [7] Since in order-production customers are directly influenced by delay in delivery, timeliness is an essential logistical performance indicator.[6] Another difference is the order of process steps. While a series-production is rigid, an order-production can be flexible and versatile. Therefore, KOCH developed a VSM method, especially for order-production. Timeliness, as well as the order of production, are assessed next to the logistical performance indicator known from the conventional VSM. The method is going to be conducted in 4 steps, shown in Table 1.[6]

Table 1: Procedure of VSM in order-production [6]

Step	Result
1 Preparation	<ul style="list-style-type: none"> – Selection of an area – Work schedules and performance data of the work systems are determined
2 Production tour	<ul style="list-style-type: none"> – Logistical performance indicators and influencing variables determined – Information about production planning is recorded
3 Data integration	<ul style="list-style-type: none"> – Material flow is shown – Information flow is shown
4 Analysis of fields of action	<ul style="list-style-type: none"> – Logistical field of actions are revealed

In step 1 “Preparation”, the production area in which the analysis is to take place is defined. Production data of completed orders are needed to determine the average performance in the number of orders per operating calendar day and the average performance in the number of hours per operating calendar day. Furthermore, a product-work system-matrix matching workplaces with products is going to be set up. While the other steps are location-independent, step 2 consists of a production tour. The data collected during the tour can be divided into three categories: (1) Information about work system, (2) logistical performance indicators with their influencing variables, and (3) planning and control information. These include for each work station e.g. the number of machines (1), the used shift system (1), inventory (2), lead time (2), estimated schedule variance due to backlog (2), sequencing (3), and capacity planning (3). Order acceptance, as well as order release, is information, that is captured production wide. Step 3 uses the information gathered in steps 1 and 2 to provide a value stream model. A product family is selected to represent the material and information flows, which are almost like a conventional VSM. The conventional VSM is enhanced with the logistical performance indicators, so timeliness, sequencing, and estimated schedule variance due to backlog are represented. In step 4, the newly created value stream card is examined, as well as order release, for possible fields of action. To find the field of improvement, KOCH states 6 questions regarding order release, inventory, sequencing, order control, and capacity planning.[6]

2.2 Process Mining

Process mining builds a bridge between traditional model-based process analysis, like the visualisation of business processes, and data-centric analysis techniques, like data mining/machine learning. Process mining utilizes event data to be able to provide insight, such as identifying bottlenecks, anticipating problems, and streamlining processes. Based on the event log and additional information three types can be carried out: [8]

- Discovery: A model is build based on the event log without a priori information.
- Conformance: A model of an already existing process is compared with the recorded event log of this process. Conformance checking is used to verify, if the recorded event log, reflecting the reality, coincides with the process model.
- Enhancement: The aim of this third type is to change or extending an a priori model.

Events include “life events”, “machine events” or “organization events”. The application of Process Mining assumes that the events considered can be recorded sequentially and that each event refers to a specific process activity and a specific process instance or case. For the use, the following data is needed or optional for each event:[8]

- Case ID – mandatory: identifies an order through the data.
- Event ID – mandatory: identifies the consecutive production steps in the data. They are linked together by the Case ID.
- Timestamp – mandatory: Gives information about the start, end and hence length of a production step.
- Activity – optional: identifies the work in each activity.
- Resource – optional: identifies the used resource in a production step (e.g. machines or employees).

3. VSM with Process Mining in Order-Production

3.1 Approach

As previously described, VSM is a standard tool to improve one’s production process, but it is also quite time-consuming and in an order-production tricky to execute. Based on the functionalities Process Mining offers, the intent of this paper is to show that Process Mining is able to conduct a VSM based on historical data containing production information of completed orders (case ID, event ID, resource, timestamps).

Furthermore, both models of the production shall be comparable to see shortcomings between reality recorded by VSM and by IT/Process Mining. Two types of Process Mining are considered to be used, to generate a model comparable to VSM. As a first step, “Discovery” ensures to visualize a model of the production steps and their sequence. After that, the “Enhancement” gives two possible perspectives. The first one is the possibility of extension, like adding KPIs to the discovered model e.g. lead time per process step. The second perspective is repairing, which helps to modify the model to reflect the reality of the data.[4] In Table 2 the already presented Table 1 is enhanced by Process Mining. In each step, Process Mining is able to support a VSM as well as to conduct to a certain extent. Subsequently, the conformance check shall be done manually since it’s a comparison of a VSM model and the Process Mining model.

Table 2: VSM in order-production enhanced by Process Mining

Step	VSM in order-production	Process Mining
1 Preparation	<ul style="list-style-type: none"> – Selection of an area. – Work schedules and performance data of the work systems are determined. 	<ul style="list-style-type: none"> – Done by the selection of the historical data.
2 Production tour	<ul style="list-style-type: none"> – Logistical performance indicators and influencing variables determined. – Information about production planning is recorded. 	<ul style="list-style-type: none"> – Logistical performance indicators can determine based on historical data.
3 Data integration	<ul style="list-style-type: none"> – Material flow is shown. – Information flow is shown. 	<ul style="list-style-type: none"> – Material flow can be generated by using Process Mining. – Most frequently used material flows are shown independently from the product family.
4 Analysis of fields of action	<ul style="list-style-type: none"> – Logistical fields of action are revealed. 	<ul style="list-style-type: none"> – Logistical fields of action are shown due to the interpretation and key figures of the model.

3.2 Case Study

The case study was performed in a company that produces different types of test facilities for combustion engines. Due to a rapid increase in demand for test facilities in the past, certain issues in the process stability became obvious. Its most apparent manifestation has been shown in the declining of the delivery reliability. Since prognoses for future demand show an increase as well, it was decided to improve the production process. Based on these facts, the decision was made, to conduct a VSM. Since additionally, digital event logs were available, they should be analysed as well.

Starting with the preparation phase of the VSM for order-production, historical production data was analysed to extract KPIs. The provided data was organized as an event log that is used in Process Mining. Therefore, it was obvious to try to use Process Mining, to shorten the time to do the on-site VSM and to gain additional insight.

The following data were available:

- Order ID which represents the test bench. It matches the intent of the case ID in Process Mining

- Production ID is to identify the different production orders to produce the given test bench. It corresponds to the event ID in process Mining.
- The Position ID sorts the activities of the production order in accordance with the indented production flow. Combined with the Production ID, it makes a unique identifiable event ID.
- Start date and end date of the activity in the event. They are used for the timestamp information.
- The work description is equivalent to the activity in Process Mining and informs about the performed work in the event step of question.
- The workplace ID and the workplace name go hand in hand with the resource ID in Process Mining.

As mentioned above the original intent was to use Process Mining in the sense of enhancement and extent to gather the necessary KPIs. Unfortunately, the data was not suitable for a detailed analysis. As mentioned in section 2.2, timestamps are necessary. In this case, case ID (a combination of the order number and production ID) and resource (workplace ID) were given. The timestamps referenced only to the day of the start and end of the mentioned event, not the actual starting and end time in minutes and hours. Additionally, the processing time was recorded. Therefore, it was not possible to bring the records in a definite chronological order. So, it is not possible to extract viable KPIs concerning lead times or execution time. Since defined production processes and flows were not available, conformance checking was out of the question as well.

As described in Table 2, process mining was used in the data integration phase to determine the most common material flow. The event log was coherent enough to show, which workplaces where frequently used and in which sequence. Process mining allowed to identify all predecessors and successors of each workplace from the perspective of the resources (workplaces). As a result, the process map was enormous and after filtering the most essential resources and cases, the basis for the most common material flow shown in Figure 1 was created. In at least 80% of the cases the black marked rectangles/workplaces are a part of the most common material flow. How often an event took that path is shown by the thickness of the arrows. In this case, it was distinguished between often (black) and seldom (grey). Grey rectangles are workplaces that are not that common in the material flow and were deemed unnecessary for the VSM.

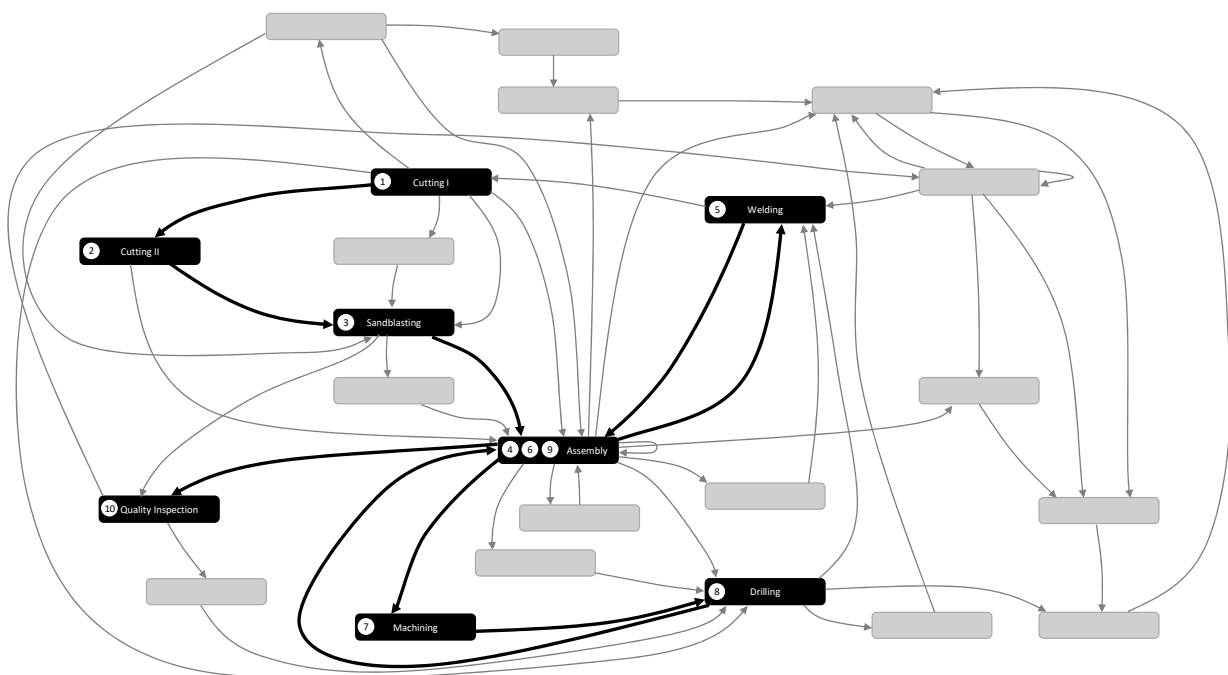


Figure 1: Most common material flow

The used sequence was extracted by analysing the process flow map of individual cases. So, it was possible to determine the repeated execution of the work at the assembly and the sequence of loops.

Using Process Mining to extract the most common material flow, was extremely helpful because there are no records of standard products. So, it would be impossible to define which order is produced on which workplace and create product families. We circumvented the issue by using Process Mining and determine the most common material flow that way.

Further detailed analysis revealed that the intended sequence of events and hence activities do not always correspond with the flow of time according to the timestamps. The possible reasons were narrowed down to two different aspects. Firstly, it could be possible that the feedback information of the timestamp was incorrect or secondly, the process steps can be switched. At the on-site VSM, it was realized that the second issue applied in most cases. Therefore, the way of how the process can be executed depends on either the respective supervisor in charge or the responsible worker. Based on his/her experience, they know how the process can be performed in a more efficient way. The identification of this issue is a typical example of enhancement by Process Mining by repairing the process itself.

4. Conclusion and Further Research

The approach of combining and replacing the VSM with Process Mining in this case study didn't lead to the expected result. But using Process Mining in order manufacturing to get the most common material flow is a considerably useful case of Process Mining applications. Without it would be impossible to define product families and start the VSM, especially in highly diversified make to order or engineer to order-productions. The application of Process Mining also showed that it is not necessarily helpful to form product families. Further research is needed to find evidence to make workflow families instead and how to assign the orders to them. In highly flexible production environments, a classification by product attributes, like already done in, for example, product families, might not be the best thing to do in order to unify the value stream. Table 3 discusses the advantages and disadvantages shown in this paper based on the case study. A combination of both methods leads to an efficient and holistic value stream model of order-production.

Table 3: Summary of advantages and disadvantages of VSM in order-production and Process Mining

	Advantages	Disadvantages
VSM in order-production	<ul style="list-style-type: none"> – Production tour supports understanding of the production – Contexts that cannot be mapped in the data can be captured 	<ul style="list-style-type: none"> – No insight into the digital footprint – One standardized product (family) is necessary – Time-consuming
Process Mining	<ul style="list-style-type: none"> – The on-site recording is more efficient due to preliminary results – First results quickly visible – No reference product (family) is needed 	<ul style="list-style-type: none"> – The result depends on data quality – converging material flows are only possible to a limited extent

Furthermore, the intentional approach should be verified in the future. Studies show that a high level of digitalization correlates with a lean organization. [1], [9] By improving data acquisition, it will be possible to improve the results of the VSM in the future. It is quite common to repeat a VSM every few years. With high-quality data, it is viable to do it automatically with Process Mining, to shorten the effort and therefore

the intervals between analyses. Well-defined and recorded timestamps will make it possible to analyse the different parts of waste in the process and improve further on them.

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Biography



Katharina Mertens (*1989) studied Industrial Logistics at Montanuniversitaet Leoben, Austria and has been a research assistant at the Chair of Economic and Business Management at Montanuniversitaet Leoben since 2017. Her research areas are production and industrial asset management, combined with data analytics.



Robert Bernerstätter (*1984) was a research assistant at the chair of Economic and Business Management at Montanuniversitaet Leoben, Austria for five years. His research area was the application of data analytics in production and asset management with focus of the effects of data quality. His doctoral thesis has the title "Maturity Model for the Evaluation of the Input Factors for Data Analytic Applications - Conceptualization on the Example of Weak Point Analysis". Since January 2020 he is working as data scientist for voestalpine Signaling Zeltweg.



Hubert Biedermann (*1953) is professor at the chair of Economic and Business Management and head of the Department of Economic and Business Management at Montanuniversitaet Leoben. His main research areas are asset management - lean smart maintenance, production management, quality and risk management. After his habilitation in industrial economics in 1989, he worked for several years in the industry and as a visiting professor. Appointed Montanuniversitaet Leoben in 1995, he held the position as a vice-rector for finance and controlling for more than 12 years.